PATENT SPECIFICATION (11) 1 595 700

1 595 700

(21) Application No. 47365/76 (22) Filed 13 Nov. 1976

(23) Complete Specification filed 11 Nov. 1977

(44) Complete Specification published 12 Aug. 1981

(51) INT CL³ F01D 5/02; F03B 13/12

(52) Index at acceptance

F1V 108 402 CS

F1S 28B2

(19)

(72) Inventor ALAN ARTHUR WELLS

(54) FLUID DRIVEN ROTARY TRANSDUCER

(71) We, THE QUEENS UNIVERSITY OF BELFAST, a corporate body established under Royal Charter, of Belfast BT7 1NN, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:—

This invention relates to rotary transducers to be driven by a working fluid such as air and particularly but not exclusively to the use of such a transducer to extract energy from the motion of the waves of the sea.

It is known that it is possible to extract energy from sea waves by allowing the waves to produce a fluctuating water level in a chamber which is preferably open to the atmosphere, thus displacing air from and drawing air into the chamber, the flow of air thus created being used to drive an air turbine. Such a chamber can be provided in a floating buoy, or be part of a larger floating structure, or of a marine structure secured to the sea bed, or of a shore stucture accessible to the waves.

It is of course desirable that the rotor of such a device should be driven only in one direction of rotation during operation, if the extraction of useful power from its rotation is to be a practical proposition.

One proposal is disclosed in British Patent Specification No. 1,014,196. This Specification discloses an arrangement which utilises a turbine of a kind which will be driven in opposite directions of rotation by air impinging on it from respectively opposite axial directions. This necessitates an arrangement of flap valves to regulate the flow of air, so that the air always flows through the rotor in the same direction of rotation. The presence of the flap valve arrangement necessitates an undesirably complicated structure and also reduces the efficiency of the turbine.

The apparatus of British Patent Specification No. 1,449,740 avoids the use of flap valves such as those described above, by using a turbine having "bucket-type" rotor blades onto which the flow of air in both axial directions is directed by means of stator blades on both sides of the turbine, so that the air impinges on the rotor blades with a substantial component of its velocity normal to the axis about which the rotor rotates, so that the turbine always rotates in the same direction. Such a turbine will have a relatively low peripheral speed since the speed of the turbine blades will be limited to a value somewhat less than that of the impining air flow, and whilst this turbine is suitable for, for example, powering a navigation light on a buoy, it is less so for generating power of a magnitude which is worth transmitting to the shore; in particular the low rotational speed makes such a device prone to undesirable irregularity of output and even to stalling.

Viewed from one aspect, the invention provides a rotary transducer comprising a rotor having a plurality of blades each of which is of aerofoil cross-section and is fixed with its plane of zero lift normal to the axis of the rotor, the arrangement being such that flow of fluid in either axial direction causes the rotor to rotate always in the same direction of rotation.

Viewed from another aspect, the invention provides a rotary transducer including a rotor and a plurality of generally radially extending rotor blades on which a working fluid is arranged to act to produce rotation of the rotor, wherein each rotor blade is fixed in position relative to the rotor and is substantially symmetrical about a plane perpendicular to the rotor axis, the blades having surfaces which are of generally aerofoil shape and being mounted with their leading edges facing in the same circumferential direction.

When the rotor of such a transducer is rotating and there is an axial flow of air through the transducer in either direction, there is a component of lift in the plane of rotation of the blade which is positive in the direction of rotation of the rotor blade, as will be explained hereinafter. In this manner, regardless of the axial direction of the flow of air incident on the rotor, the rotor will always be rotated in the same direction.

When the rotor is stationary, the rotor will start to rotate when an air flow occurs in the

axial direction of the rotor. This is because the blades of the rotor which are of aerofoil cross-section have a larger radius of curvature at the leading edge than at the trailing edge thereof, and the reduction of pressure caused by the flow of air will act on a larger area at the leading edge of the blade than at the trailing edge. This phenomenon produces only a weak force, but it is sufficient to start rotation of the rotor, whereafter the mechanism outlined above comes into effect. It will thus be appreciated that a comparatively thick, blunt blade would have good self-starting characteristics. However, a thinner blade capable of operating at high speed is preferred as providing a more efficient rotor. The blade profile at present preferred is that referred to as NACA 64/009, NACA being the United States National Advisory Committee on Aeronautics. This is, however, only one example of many similar profiles which could be used, for example NACA 0009 and 0012.

The solidity factor of the rotor, which is defined as that proportion of the area of the circle swept by the rotor blades which is occupied by the rotor blades, is preferably less than 0.5, more preferably in the range 0.3 to 0.4.

The transducer may have guide vanes on at least one side of the rotor. Preferably, guide vanes are arranged on both sides of the rotor. Such guide vanes cause air to flow substantially axially through the rotor. The guide vanes may lie in planes containing the axis of the rotor, but they are preferably inclined to such planes, e.g. at an angle of up to 30° the edges of the guide vanes adjacent the rotor being more advanced in the direction of rotation of the rotor than the opposite edges thereof.

The invention further provides apparatus for extracting energy from the cyclic motion of a body of water, comprising a transducer as described above arranged such that said cyclic motion of the body of water causes rotation of the rotor.

Preferably the transducer is positioned in a duct which is part of a housing surrounding part of the body of water, the lower end of the housing being open and submerged. In such an arrangement it is preferable that air above the level of the water within the housing is caused to flow through the transducer in accordance with variations in the level of water in the housing.

The apparatus preferably comprises a floating buoy, although it could form part of a shore structure, part of a larger floating structure or be connected to the sea bed. The transducer is preferably used to generate electricity by means of a generator driven by the rotor, although it could also be used to drive a pump or other suitable means of power conversion.

When such an apparatus is in the form of a buoy, a mass of water confined by it heaves in cyclic motion. As the water level rises and falls air is drawn through the transducer and, owing to the construction of the transducer in accordance with the invention, air flow in either direction always causes the rotor to rotate in the same direction.

Preferably the transducer is mounted in the throat of a convergent-divergent nozzle with its axis of rotation concident with the axis of the nozzle, the nozzle communicating the interior of the buoy with atmosphere.

The lift or axial thrust which is generated at the rotor is proportional to the instantaneous axial velocity of the air through it, averaged over its cross-section, so that linear damping is impressed upon the air column within the buoy, hence upon the heaving motion of the buoy itself, which motion is also controlled by the mass of the buoy (including that of entrained water), the stiffness related to heaving motion (arising from the waterline cross-section of the buoy), the damping as defined above, and the cyclic heave disturbing force from the incident wave system. Insofar as a wave system has a characteristic spectrum of wave components of different wavelengths and angular velocities, the natural frequency of heave oscillation of the buoy should correspond with that of the wave component having the greatest product of power potential and probability of occurrence (over an annual or longer period), or somewhat greater natural frequency than this, so that a suitable compromise is obtained between three factors namely, exploitation of power amplification by resonance, efficient power extraction from the more probable but less powerful high frequency waves, and a high degree of rejection of power from non-resonant storm waves of low frequencies.

In an embodiment of the invention to be described, the optimal inertial mass of the buoy is larger than can be accommodated within the buoyancy space and a subsidary chamber, which is flooded with water and to which an anchor cable is secured, is attached below the buoy. The extra inertial mass is thereby made to be approximately neutrally buoyant. Such an ancillary mass to which the anchor cable is secured can then also provide the facility of a kedge whereby the anchor cable force is constrained towards the horizontal at all times (such that the anchor is not dragged from its penetrated position), and provision is allowed for limited horizontal as well as vertical cyclic motion of the buoy, due to wave action.

A set of guide vanes as mentioned earlier is preferably arranged at least on that side of the transducer in communication with the interior of the buoy. This is because when air is drawn through the transducer into the buoy, a swirl is induced in the air, so that when this air is forced out of the buoy, this swirl

tends to persist. It is therefore desirable to improve the efficiency of the transducer by eliminating, or at least substantially reducing this effect.

A plurality of buoys as described above may be interconnected to form a straight or curved line, or a ring. However, the buoys are more efficient when moored in isolation, and it is therefore preferred that the buoys are spaced from one another by approximately six buoy diameters.

It may be desirable to provide a buoy having a plurality of rotary transducers working in parallel air streams. This would allow the air capacity to be increased whilst keeping the air flow over the blades of each rotor subsonic. This arrangement also has the advantage that the flow to one or more of the transducers could be shut off when the wave height is small, whereby the range of peak flow rates for which there is useful work output is effectively doubled.

In addition it may also be desirable to provide a plurality of rows of blades in series on a common rotor shaft, in order to obtain an increased pressure drop.

In the accompanying drawings: —

Figure 1 is a diagram illustrating the theory of the mode of operation of a rotary transducer in accordance with the invention;

Figure 2 shows a plan of an embodiment of a rotary transducer in accordance with the invention;

Figure 3 shows an end elevation of the apparatus of Figure 2;

Figure 4 shows a transducer incorporating the apparatus of Figures 2 and 3 mounted in a buoy; and

Figure 5 is a general view of a buoy embodying the present invention.

In Figure 1, a rotor blade is shown in cross-section, and can be seen to be of symmetrical aerofoil section. The velocity of the particular portion of the blade shown is V, thus producing an effective flow of air with a velocity component V in the direction opposite to the direction of rotation, as shown in the drawing. When air is flowing axially downwardly through the rotor with a velocity U_1 the resultant direction of air incident on the rotor blade is I_1. When air is flowing axially upwardly with a velocity U_2, the direction of air incident on the rotor blade is I_2. A lift is created in the direction normal to the incident air at the blade; L_1 with the air flowing downwardly and L_2 with the air flowing upwardly. It will be seen that both L_1 and L_2 have a component in the plane of rotation of the blade which is positive in the direction of rotation of the rotor blade. Thus, regardless of the axial direction of the flow of air incident or the rotor blade, it will always cause the rotor to which it is attached to rotate in the same direction.

As shown in Figures 2 and 3, a transducer in accordance with the invention comprises a rotor 1 having two fixed blades 2, each of which has a symmetrical aerofoil cross-section. The blades are arranged so that the plane of zero lift, i.e. the plane of symmetry (horizontal in Figure 3) lies in a plane normal to the axis of the rotor; that is, the chords of the blades are aligned in the direction of rotation. Of course, the blades have their leading edges pointing in the same circumferential direction.

Figure 4 shows the apparatus of Figures 2 and 3 bolted to the shaft 3 of an electrical generator 4. The generator is mounted in a vertical duct in the form of a convergent-divergent nozzle 5 by means of three guide vanes or stator blades, 6 axially spaced above the transducer. The generator is mounted in such a position that the transducer is situated at the throat of the nozzle with the rotor coaxial with the nozzle. A further arrangement of three guide vanes 7 is mounted in the nozzle axially spaced below the rotor 1. The vanes 6 and 7 serve to reduce swirl in air flows passing axially through the nozzle. Such air flows serve to rotate the rotor as described above, the rotor rotating the shaft 3 whereby the generator 4 produces power which can be collected in a known manner.

Figure 5 shows a buoy 8 incorporating the arrangement shown in Figure 4. The buoy 8 is quasi-spherical, having the convergent-divergent nozzle 5 described above at the top and having an open base 9. The buoy is assembled from a plurality of sections 10, made of fibre-reinforced material. Glass or other strong fibres and a polymeric or inorganic cement matrix are suitable. At least some of the sections 10 are provided with a buoyancy pad 11 in the interior of the buoy. The buoyancy pads may be made of rigid polymeric foam. The buoy 8 is secured to a subsidiary chamber 12 by means of rigid members 14. This chamber can be flooded, the water entering the chamber through a port 13 in order to increase the inertial mass of the buoy. Moreover, since substantially all of this mass is contributed by the water contained in the chamber 12, the mass is neutrally buoyant. In order to assist in maintaining the orientation of the buoy in use, caps 15 and 16 of rigid polymeric foam and concrete respectively may be provided in chamber 12. Legs 17 are provided so that the buoy may be stood upright on the ground.

When the buoy is to be used, it is towed out to the desired location. The chamber 12 is flooded and the buoy is moored by means of mooring chains attached to the chamber 12. The buoy constitutes a housing or conduit which surrounds a part of the body of water — i.e. the sea. The lower end 9 of the buoy is of course submerged, there being a column of water within the buoy. As waves pass the buoy, the water column contained in the buoy

8 oscillates, thus pumping air above the water alternately upwardly and downwardly through the transducer. This causes the rotor 1 to rotate as described above, thus causing generator 4 to generate electricity.

WHAT WE CLAIM IS:—

1. A rotary transducer comprising a rotor having a plurality of blades each of which is of aerofoil cross-section and is fixed with its plane of zero lift normal to the axis of the rotor, the arrangement being such that flow of fluid in either axial direction causes the rotor to rotate always in the same direction of rotation.

2. A transducer as claimed in claim 1, having a solidity factor of less than 0.5.

3. A transducer as claimed in claim 2 having a solidity factor in the range 0.3 to 0.4.

4. A transducer as claimed in claim 1, 2 or 3, having only two of said blades.

5. A transducer as claimed in claim 1, 2 or 3, including a plurality of rows of said blades mounted in series on a common rotor.

6. A transducer as claimed in any preceding claim, having guide vanes on at least one side of the rotor.

7. A transducer as claimed in claim 6 having said guide vanes on both sides of the rotor.

8. A transducer as claimed in claim 6 or 7 wherein the guide vanes are inclined to planes containing the axis of the rotor.

9. A transducer as claimed in claim 8 wherein the angle of inclination of the guide vanes is up to 30°.

10. A transducer as claimed in claim 6 or 7 wherein the guide vanes lie in planes containing the axis of the rotor.

11. A transducer as claimed in any preceding claim, wherein the blades are of symmetrical cross-section.

12. A transducer as claimed in any preceding claim including an electrical generator arranged to be driven by the rotor.

13. A transducer as claimed in claim 12, and any of claims 6 to 10, wherein the generator is supported by the guide vanes.

14. A rotory transducer, substantially as hereinbefore described with reference to Figures 1 to 3 of the accompanying drawings.

15. A rotary transducer as claimed in any of claims 1 to 13, positioned in a duct through which the fluid flows.

16. A transducer as claimed in claim 15, wherein the rotor is coaxial with the duct.

17. A transducer as claimed in claim 15 or 16 wherein the duct is in the form of a convergent-divergent nozzle and the transducer is mounted in the throat of the nozzle.

18. A transducer as claimed in claim 15, 16 or 17, substantially as hereinbefore described with reference to Figures 1 to 4 of the accompanying drawings.

19. Apparatus for extracting energy from the cyclic motion of a body of water, comprising a transducer as claimed in any preceding claim arranged such that said cyclic motion of the body of water causes rotation of the rotor.

20. Apparatus as claimed in claim 19, and any of claims 15 to 18, wherein the duct is part of a housing surrounding part of the body of water, the lower end of the housing being open and submerged.

21. Apparatus as claimed in claim 20, wherein air above the level of the water within the housing is caused to flow through the transducer in accordance with variations in the level of water in the housing.

22. Apparatus as claimed in claim 20 or 21 wherein the duct is vertically disposed.

23. Apparatus as claimed in any of claims 19 to 22, being secured to the sea bed.

24. Apparatus a claimed in any of claims 19 to 22, being in the form of a floating buoy.

25. Apparatus as claimed in claim 19 and any of claims 15 to 18, wherein the apparatus is in the form of a buoy, the interior of which confines a mass of water and is connected to atmosphere via the duct, cyclic movement of the mass of water causing air to flow through the transducer.

26. Apparatus as claimed in claim 25 wherein the buoy has an open bottom and the mass of water is a portion of the aforesaid body of water which is surrounded by the buoy.

27. Apparatus as claimed in claim 24, 25 or 26, including a subsidiary chamber which is flooded with water to increase the inertial mass of the buoy.

28. Apparatus for extracting energy from the cyclic motion of a body of water, substantially as hereinbefore described with reference to the accompanying drawings.

29. A rotary transducer including a rotor and a plurality of generally radially extending rotor blades on which a working fluid is arranged to act to produce rotation of the rotor, wherein each rotor blade is fixed in position relative to the rotor and is substantially symmetrical about a plane perpendicular to the rotor axis, the blades having surfaces which are of generally aerofoil shape and being mounted with their leading edges facing in the same circumferential direction.

30. A rotary transducer as claimed in claim 29 wherein the rotor is mounted coaxially within a conduit incorporates stator blades axially spaced from the rotor in both directions, the stator blades being inclined in such a manner as to decrease or eliminate the swirl in the flow of working fluid.

31. A rotary transducer as claimed in claim 29 or 30 wherein the rotor is located within a vertical conduit having its lower end sub-

merged in water, the rotor being mounted co-axially within the conduit in air above the level of the water such that variations in the level of the water in the conduit produce a cyclic flow of air past the rotor blades.

For the Applicants,
FRANK B. DEHN & CO.,
Imperial House,
15—19 Kingsway,
London, WC2B 6UZ.

Printed for Her Majesty's Stationery Office by the Courier Press, Leamington Spa, 1981.
Published by the Patent Office, 25 Southampton Buildings, London, WC2A 1AY, from which copies may be obtained.

FIG.1.

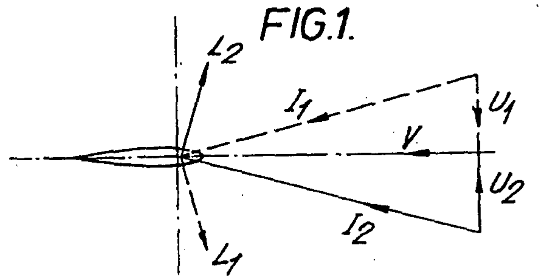
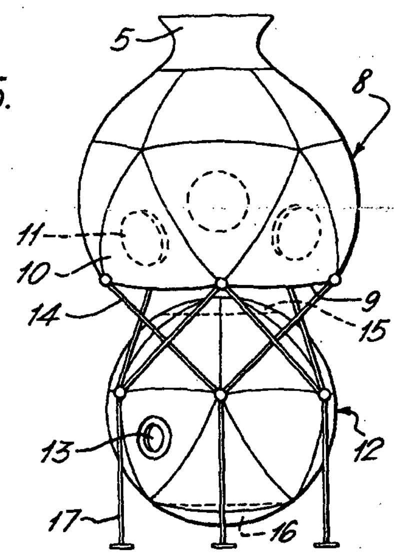


FIG.5.



1595700 COMPLETE SPECIFICATION

2 SHEETS *This drawing is a reproduction of the Original on a reduced scale*

Sheet 2

FIG.3.

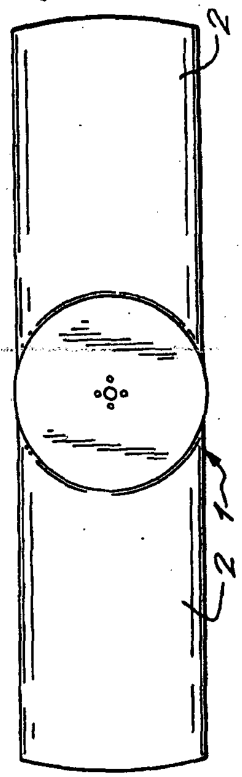


FIG.2.

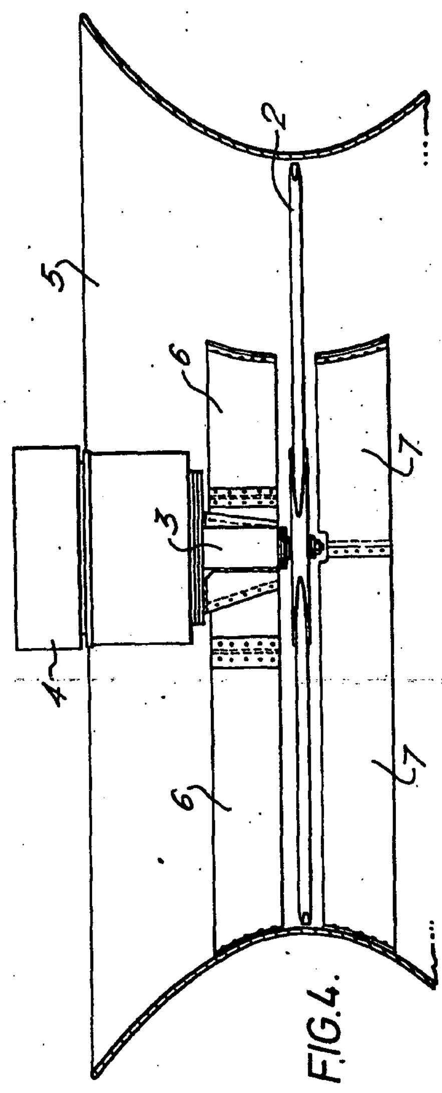


FIG.4.